Claims

What is claimed is:

1. A method for designing an actively cooled turbine blade having an internal fluid passage, comprising:

determining interior heat transfer at an interior area of an interior surface of the fluid passage;

determining external heat transfer at an exterior area of an exterior surface adjacent the interior area;

comparing the internal and external heat transfer; and

redesigning and reevaluating the design of the interior fluid passage until the internal and external heat transfer are equal.

2. The method of claim 1, wherein determining comprises:

supplying the internal fluid passage with a fluid at a first temperature until the turbine blade reaches a first steady thermal state;

measuring and recording the internal fluid pressure and internal and external fluid temperature and flow rate;

supplying the internal fluid passage with a fluid at a second temperature until the turbine blade reaches a second steady thermal state; and

measuring and recording the exterior surface temperature, time between first and second steady thermal state, and internal and external fluid temperature and flow rate.

3. The method of claim 1, wherein the method further comprises

providing a distance between the internal surface and the corresponding external surface, and heat capacity, density, and thermal conductivity of the material comprising the component and

calculating a heat transfer coefficient of the internal surface of the internal fluid passage.

4. The method of claim 3, wherein said calculating of a heat transfer coefficient of the internal surface of the internal fluid passage comprises:

calculating a heat transfer coefficient of the internal surface of the internal fluid passage using the following equations:

$$h_i = (T_i - T_o)^* C_p^* p^* V]/[A_i^* t_{imaged}^*(T_a - T_i)]$$

where: T_a = temperature of the internal fluid at point i and of a small arbitrary area A_i through which a tangent line to the internal surface of the internal passage passes;

h_i = an internal heat transfer coefficient at the internal surface of the internal passage at area A_i through which the same line referenced in the definition of T_a passes;

T_i = an internal temperature at the internal surface of the internal passage at area A_I;

T_o = an external temperature of the component at a point o and of a small area A_o through which the same line referenced in the definition of T_a passes, as measured at some time t_{imaged} during the test t_0, or zero time;

w = a distance between points i and o, or the internal surface and external surface of the component (wall thickness), through the line tangent to A_i and the outer surface of the component;

V = a volume defined by A_i*w, measured in (m^3);

E = the energy stored in the volume V around the line drawn referenced in the definition of T_a after the time t_{test}, measured in Joules, or (J);

$E_{conduction}$ = energy imparted to the component due to conduction, as conducted through the small volume V;

$E_{convection}$ = energy imparted to the component at the area A_i by the internal fluid through convection;

C_p = heat capacity of the material of the component;

p = density of the material comprising the component; k = the thermal conductivity of the material comprising the component;

h_o = external heat transfer of the external surface at area A_o; and

T_b = temperature of the external fluid, wherein: $E_{conduction}$, or E, is defined by $E_{conduction} = E = k*A_i*t_{imaged}*(T_i - T_o)/w$.

5. A method for optimizing the performance of a turbine engine, comprising:

determining a heat transfer coefficient of an internal surface of an internal fluid passage of a turbine blade; and

balancing heat transfer between the internal surface of the internal fluid passage and the internal fluid with an external surface of the turbine blade and an external fluid.

6. The method of claim 5, wherein said determining comprises:

supplying the internal fluid passage with a fluid at a first temperature until the turbine blade reaches a first steady thermal state;

measuring and recording the internal fluid pressure and internal and external fluid temperature and flow rate;

supplying the internal fluid passage with a fluid at a second temperature until the turbine blade reaches a second steady thermal state;

measuring and recording the exterior surface temperature, time between first and second steady thermal state, and internal and external fluid temperature and flow rate.

7. The method of claim 5, wherein the method further comprises

providing a distance between the internal surface and the corresponding external surface, and heat capacity, density, and thermal conductivity of the material comprising the component and

calculating a heat transfer coefficient of the internal surface of the internal fluid passage.

8. The method of claim 7, wherein said calculating of a heat transfer coefficient of the internal surface of the internal fluid passage comprises:

calculating a heat transfer coefficient of the internal surface of the internal fluid passage using the following equations:

$$h_i = (T_i - T_o)^* C_p{}^*p^*V]/[A_i{}^*t_{imaged}{}^*(T_a - T_i)]$$

where: T_a = temperature of the internal fluid at point i and of a small arbitrary area A_i through which a tangent line to the internal surface of the internal passage passes;

h_i = an internal heat transfer coefficient at the internal surface of the internal passage at area A_i through which the same line referenced in the definition of T_a passes;

T_i = an internal temperature at the internal surface of the internal passage at area A_I;

T_o = an external temperature of the component at a point o and of a small area A_o through which the same line referenced in the definition of T_a passes, as measured at some time t_{imaged} during the test t_0, or zero time;

w = a distance between points i and o, or the internal surface and external surface of the component (wall thickness), through the line tangent to A_i and the outer surface of the component;

V = a volume defined by A_i*w, measured in (m^3);

E = the energy stored in the volume V around the line drawn referenced in the definition of T_a after the time t_{test}, measured in Joules, or (J);

$E_{conduction}$ = energy imparted to the component due to conduction, as conducted through the small volume V;

$E_{convection}$ = energy imparted to the component at the area A_i by the internal fluid through convection;

C_p = heat capacity of the material of the component;

p = density of the material comprising the component; k = the thermal conductivity of the material comprising the component;

h_o = external heat transfer of the external surface at area A_o; and

T_b = temperature of the external fluid, wherein: $E_{conduction}$, or E, is defined by $E_{conduction} = E = k*A_i*t_{imaged}*(T_i - T_o)/w$.

9. An apparatus comprising:

a storage medium comprising a plurality of programming instructions to enable a designer to use the apparatus to

determine interior heat transfer at an interior area of an interior surface of an internal fluid passage of an actively cooled turbine blade, based at least in part on thermal data collected for the turbine blade;

determine external heat transfer at an exterior area of an exterior surface adjacent the interior area; and

compare the internal and external heat transfer to determine if they are equal; and

at least one processor coupled to the storage medium to execute the programming instructions.

10. The apparatus of claim 9, wherein the apparatus further comprise a thermal imager equipped to allow the designer to

supply the internal fluid passage with a fluid at a first temperature until the turbine blade reaches a first steady thermal state;

measure and record the internal fluid pressure and internal and external fluid temperature and flow rate;

supply the internal fluid passage with a fluid at a second temperature until the turbine blade reaches a second steady thermal state; and

measure and record the exterior surface temperature, time between first and second steady thermal state, and internal and external fluid temperature and flow rate.

11. The apparatus of claim 9, wherein the programming instructions further enable the designer to provide a distance between the internal surface and the

corresponding external surface, and heat capacity, density, and thermal conductivity of the material comprising the component and calculate a heat transfer coefficient of the internal surface of the internal fluid passage.

12. The apparatus of claim 11, wherein the programming instructions are designed to calculate, as part of said calculating,

$$h_i = (T_i - T_o)^* C_p{}^*p^*V]/[A_i{}^*t_{imaged}{}^*(T_a - T_i)]$$

where: T_a = temperature of the internal fluid at point i and of a small arbitrary area A_i through which a tangent line to the internal surface of the internal passage passes;

h_i = an internal heat transfer coefficient at the internal surface of the internal passage at area A_i through which the same line referenced in the definition of T_a passes;

T_i = an internal temperature at the internal surface of the internal passage at area A_I;

T_o = an external temperature of the component at a point o and of a small area A_o through which the same line referenced in the definition of T_a passes, as measured at some time t_{imaged} during the test t_0, or zero time;

w = a distance between points i and o, or the internal surface and external surface of the component (wall thickness), through the line tangent to A_i and the outer surface of the component;

V = a volume defined by A_i*w, measured in (m^3);

E = the energy stored in the volume V around the line drawn referenced in the definition of T_a after the time t_{test}, measured in Joules, or (J);

$E_{conduction}$ = energy imparted to the component due to conduction, as conducted through the small volume V;

$E_{convection}$ = energy imparted to the component at the area A_i by the internal fluid through convection;

C_p = heat capacity of the material of the component;

p = density of the material comprising the component; k = the thermal conductivity of the material comprising the component;

h_o = external heat transfer of the external surface at area A_o; and

T_b = temperature of the external fluid, wherein: $E_{conduction}$, or E, is defined by $E_{conduction} = E = k^*A_i^*t_{imaged}^*(T_i - T_o)/w$.

13. An apparatus comprising

a storage medium having stored therein a plurality of programming instructions to enable a designer to

determine a heat transfer coefficient of an internal surface of an internal fluid passage of a turbine blade; and

balance the heat transfer between the internal surface of the fluid passage and the internal fluid with an external surface of the turbine blade and an external fluid; and

at least one processor coupled to the storage medium to execute the programming instructions.

14. The apparatus of claim 13, wherein the apparatus further comprises a thermal imager equipped to enable the designer to

supply the internal fluid passage with a fluid at a first temperature until the turbine blade reaches a first steady thermal state;

measure and record the internal fluid pressure and internal and external fluid temperature and flow rate;

supply the internal fluid passage with a fluid at a second temperature until the turbine blade reaches a second steady thermal state;

measure and record the exterior surface temperature, time between first and second steady thermal state, and internal and external fluid temperature and flow rate.

15. The apparatus of claim 13, wherein the programming instructions further enable the designer to provide a distance between the internal surface and the

corresponding external surface, and heat capacity, density, and thermal conductivity of the material comprising the component and calculate a heat transfer coefficient of the internal surface of the internal fluid passage.

16. The apparatus of claim 15, wherein the programming instructions are designed to calculate, as part of said calculating,

$$h_i = (T_i - T_o)^* C_p{}^*p^*V]/[A_i{}^*t_{imaged}{}^*(T_a - T_i)]$$

where: T_a = temperature of the internal fluid at point i and of a small arbitrary area A_i through which a tangent line to the internal surface of the internal passage passes;

h_i = an internal heat transfer coefficient at the internal surface of the internal passage at area A_i through which the same line referenced in the definition of T_a passes;

T_i = an internal temperature at the internal surface of the internal passage at area A_i;

T_o = an external temperature of the component at a point o and of a small area A_o through which the same line referenced in the definition of T_a passes, as measured at some time t_{imaged} during the test t_0, or zero time;

w = a distance between points i and o, or the internal surface and external surface of the component (wall thickness), through the line tangent to A_i and the outer surface of the component;

V = a volume defined by A_i*w, measured in (m^3);

E = the energy stored in the volume V around the line drawn referenced in the definition of T_a after the time t_{test}, measured in Joules, or (J);

$E_{conduction}$ = energy imparted to the component due to conduction, as conducted through the small volume V;

$E_{convection}$ = energy imparted to the component at the area A_i by the internal fluid through convection;

C_p = heat capacity of the material of the component;

p = density of the material comprising the component; k = the thermal conductivity of the material comprising the component;

h_o = external heat transfer of the external surface at area A_o; and

T_b = temperature of the external fluid, wherein: $E_{conduction}$, or E, is defined by $E_{conduction} = E = k*A_i*t_{imaged}*(T_i - T_o)/w$.